Proposed Measurement of the Parity-Violating Neutron Spin Rotation in ^{4}He

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Abstract. Weak interactions between u and d quarks induce weak interactions between nucleons. These weak-interaction effects can be isolated from strong interactions using parity-violation (PV). The nucleon-nucleon (NN) weak interaction amplitudes are constrained by neither theory nor experiment. We describe a proposed measurement of PV neutron spin rotation in liquid helium ϕ_{PV}(n,α) that is scheduled to run in 2006 with a sensitivity of 3×10^{-7} rad/m.

Keywords: **NN** weak interaction, hadronic weak interaction, parity violation, spin rotation, cold neutrons, liquid helium, superfluid liquid helium, supermirror, ionization chamber.
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MOTIVATION

After four decades of study, the hadronic weak interaction still remains a mystery. Both existing experimental data and theoretical predictions are inconsistent. Historically, the NN weak interaction has been described in terms of an effective meson exchange model in which a single meson couples between nucleons via the strong interaction at one vertex and the weak interaction at the other. Effective PV meson-nucleon couplings can be calculated directly from the Standard Model using the DDH [1] valence quark model and are denoted by f_π, h_ρ^0, h_ρ^1, $h_\rho'^1$, h_ρ^2, h_ω^0 and h_ω^1, where subscripts denote exchanged mesons and superscripts indicate isospin change. A systematic analysis of the NN weak interaction using an effective field theory approach and chiral perturbation theory has appeared recently [2] and should provide a model–independent connection to QCD. The NN weak amplitudes are neither well determined from theory nor from experimental data (Figure 1). Constraints from a measurement of ϕ_{PV}(n,α) would be orthogonal in isospin space to both the ^{133}Cs anapole moment measurement [3] and the transmission asymmetry of protons through ^{4}He [6]. ϕ_{PV}(n,α) is sensitive mainly to a sum of f_π and h_ρ^0 [10]. When combined with data from npdγ – which is primarily sensitive to f_π [11] – a ϕ_{PV}(n,α) measurement can be used to determine the h_ρ^0 coupling in the DDH model.

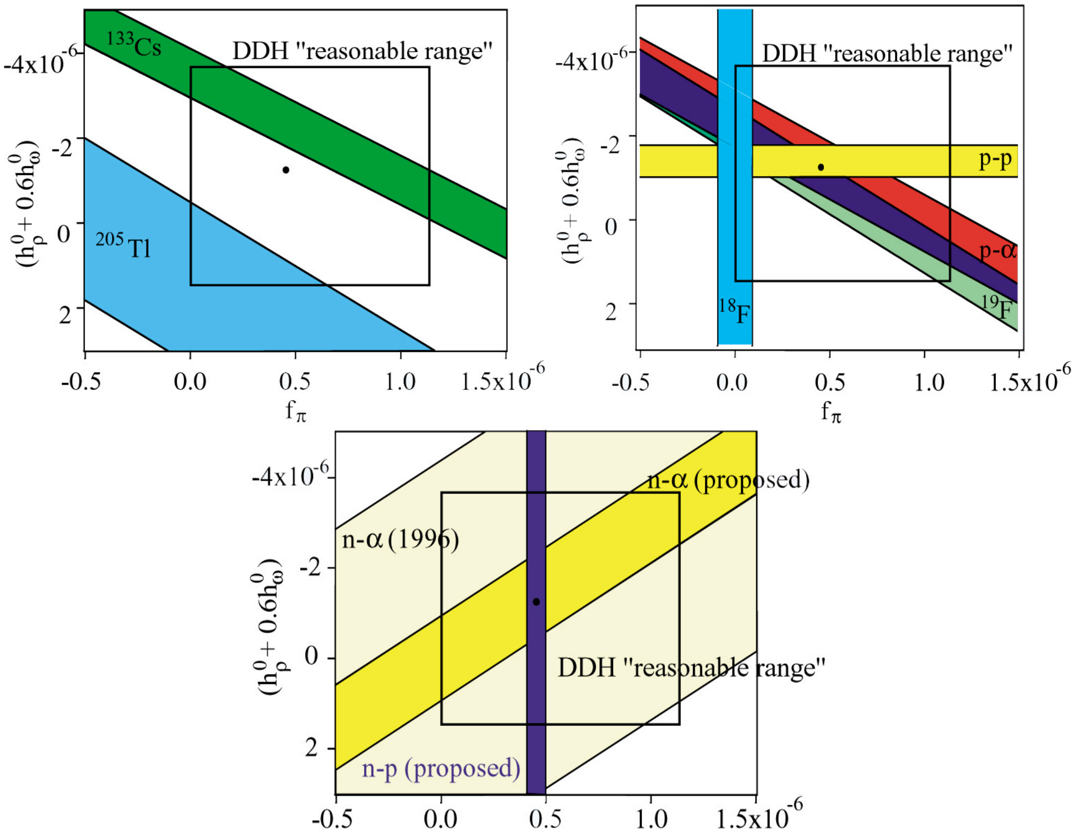

FIGURE 1. Two-dimensional slice of a linear combination of weak couplings: extracted from experiments in atomic physics (upper left [3,4]), and from light and medium nuclei (upper right [5-8]). The box represents the DDH model "reasonable range"; projected sensitivity of the proposed n-^{4}He spin rotation, npdγ, and previous version of n-^{4}He spin rotation (lower [9]). The width of the band in the plot corresponds to the proposed experimental measurement sensitivity of 3×10^{-7} rad/m.

EXPERIMENT

Parity violation causes the polarization vector of a transversely-polarized neutron beam to "corkscrew" about its momentum vector as it passes through matter. This PV phenomenon [12] can be described in terms of a helicity-dependent neutron refractive index. Positive and negative helicity states accumulate different phase shifts as they pass through matter. The relative phase shift yields an observed rotation. The angle of PV neutron spin rotation in helium is expected to be ~10^{-7} rad/m [10] and is energy independent. However, this effect can be easily dominated by the much bigger parity-conserving (PC) spin rotation due to the Larmor precession of the neutron spin about a magnetic field. The challenge of suppressing the magnetic field in the target region is accomplished by using three coaxial μ-metal shields with magnetometer-controlled trim coils within the target and should suppress the fields to less than 2nT. Still, cold neutrons (5Å) will Larmour precess by an angle 100 times larger than the PV signal. This PC signal will be further suppressed by the design of the LHe target itself. The target is split into forward and backward sections that are separated by a pi-coil, which which will precess the neutron spin by 180°. Each of these sections is further subdivided into left and right halves. By alternately filling and draining the forward-right and backward-left target chambers with LHe (and vice versa for the other two chambers) the PC signal can be suppressed by subtracting the signal from left and right halves. The spin rotation angle is measured using a supermirror polarizer/analyzer pair and ^{3}He ionization chamber [13] and is determined by effectively flipping the direction of the analyzer and then recording the asymmetry between the target states. Sizes of systematic effects have been estimated assuming a longitudinal magnetic field of 10nT. These effects are due to diamagnetism, the n-^{4}He neutron optical potential, and small-angle scattering in LHe. Each of these effects is at least one order of magnitude smaller than the sensitivity goal of this experiment. To verify these estimates, we will increase the magnetic field to 100μT during systematic checks. A more detailed description of physics of this experiment together with technical details can be found [14].

SUMMARY/GOALS

The experimental apparatus has been upgraded since the measurement in 1996 with a new LHe target capable of using superfluid helium, additional magnetic shielding, and improved cryogenic system. The statistical sensitivity goal is to reach 3×10^{-7} rad/m in three months of data taking.

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